13p.

NASA TT F-8117 X63-11474

STRUCTURE OF THE MOON'S SURFACE AND INVESTIGATION OF THE FIRST PHOTOGRAPHS OF ITS FAR SIDE

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON January 1962

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STRUCTURE OF THE MOON'S SURFACE AND INVESTIGATION OF THE FIRST PHOTOGRAPHS OF ITS FAR SIDE

(Struktura poverkhnosti Luny i issledovaniye pervykh fotografiy yeye obratnoy storony)

(Translated from Collection (Sbornik): Iskusstvennyye Sputniki Zemli (Artificial Earth Satellites). Publishing House of Academy of Sciences, USSR, No. 9, pp 56-61, Moscow, 1961)

By N. P. Barabashov

The productive study of the lunar surface had begun after the telescope was invented in 1610. As is well known, at present the part of the Moon visible from the Earth is rather well studied. Telescopic investigations revealed many cirques and craters, enormous plains called lunar seas, mountain ranges, isolated elevations, and clear bands (light rays), radially spreading from certain craters. The nature of these rays has not yet been clarified. Besides, numerous fissures (some of them very broad and deep) are noted on the Moon's surface. However, even now there is no unique opinion about the state in which the surface layers of the Moon are found, and what sort of rocks compose them.

A number of astronomers consider that the lunar surface consists of rocks different from those forming the surface of the Earth. However, such assumptions are difficult to accept, for the close kinship and similar conditions of formation of the Earth and of the Moon make the absence of the Moon of terrestrial-like rocks quite improbable and the same can be said about the presence of kinds unknown on Earth.

Other investigators hold to the opinion that rocks forming the lunar surface are mainly volcanic rocks known on Earth but the surface of which has been considerably modified by meteoritic impacts and other cosmic factors such as cosmic, ultraviolet and X-rays. One must agree with the fact that the effect of such factors on the Moon, almost devoid of atmosphere, must play a known part in reworking the material constituting the lunar surface.

L. N. Radlova (1) maintained that the lunar surface is completely mantled by a layer of material of meteoritic origin. He considered the dust mantle of the Moon to be semi-transparent or not quite continuous, so that the underlying surface may be visible through it as if it were translucent.

A. Dollfuss (2) assumes that the entire Moon is covered by volcanic ashes of various luminosity, and consisting of multi-sized grains. This difference in luminosity and in grain size is also the cause of difference in the luminosity of lunar formations. The possibility of such a continuous covering of plains as well as of lunar mountains' slopes by ashes meets with substantial difficulties.

N. N. Sytinskaya (3) considers that the entire visible lunar surface is covered with a layer having formed through the disintegration of rock formations composing the Moon. The basic factor of such metamorphosis is the impact on the lunar surface by meteoritic bodies of various sizes. We assume that the mantle so obtained is not dust, but a porous, spongy sintered slag (of volcanic type), having formed under the effect of high temperature developing from meteoritic impacts.

The low reflection capacity and the small difference in the color of its various surface sectors constitute the fundamental and the most perceptible characteristic of the lunar surface. It appears that the greatest gradation of reflecting capability (ratio of reflecting capability of lunar surface's darkest spots to those of the brightest region during full Moon) constitutes only 1 : 3.46, with the brightest regions having a 0.180 luminosity, and the darkest - 0.052. As to the coloring, if one takes in the first approximation the standard color indicator to express it, i. e. the difference between the photographic and visual stellar magnitude, it is found that it falls within the 0.92 to 1.12 range. If we plot the minimum and maximum luminosity of lunar details on the x-axis, the maximum and minumum color indicator - on the y-axis, we shall obtain on the luminosity-coloring plane a rectangular region in which all lunar objects are included according to luminosity as well as to color indicator. Here, it is appropriate to note that the surface of the rectangle obtained is small compared with the surface in which terrestrial rocks may be located, and that certain of the rocks occurring within the rectangle may not correspond to the lunar types, for they may have a different energy distribution in various regions of the spectrum, and they may also differ in other characteristics (e.g., polarization, light reflection law, density etc.). The simultaneous comparison method according to luminosity and color was applied by N. N. Sytinskaya (3) who concluded that not one of the rock types may be recognized as conformable with the lunar surface.

Based on studies adduced in (4), it was found that the following rocks get into the above-indicated "lunar" rectangle: tufaceous lava, liparite, quartz-keratophyre, bestonite and tuffs. The other types of rocks subjected to measurements did not appear in the rectangle.

As already noted, not all rocks occurring in the "lunar" triangle may be considered to be components of the lunar surface (because of their polarization properties, laws of reflection etc.). Based on the study of polarization properties of the lunar surface and terrestrial rocks, and also of energy distribution in the 3600 to 7500 Å spectral region, we may conclude that only tuff-like rocks and volcanic ashes may be compared with rocks that form the lunar surface.

Our research shows that rocks undergoing fusion in vacuum under atmospheric pressure cannot resemble lunar objects: they become almost colorless and have a polarization considerably exceeding that of lunar surface rocks. The fused and subsequently carved rock surfaces are also characterized by an excessive polarization. The porosity of the lunar surface is about 0.80.

Observations that were made in 1918 have shown that the law of light reflection from the lunar surface differs sharply from the Lambert law, about valid for ideally mat surfaces. It was revealed that the brightness maximum of any arbitrarily located lunar sea sector is reached near the full Moon phase, when $\alpha \approx 0$ and $i \approx \varepsilon$. (i and ε being the angles of incidence and reflection respectively), i.e., when the ray, incident to a lunar sea sector, and the one reflected from it, run along almost the same direction. It was shown later by A. V. Markov (5) that mountain regions also have the peculiarity, which thus is not limited to lunar seas. It appeared that if the lunar surface part lies near the western edge of the lunar disk, its brightness increases slowly, reaches the maximum at full Moon, and then decreases rapidly. As for the part near the eastern edge of the lunar disk, the opposite phenomenon takes place: brightness quickly increases, reaching a maximum at full Moon, and then decreasing slowly. For the lunar disk's central meridian, the ascending and descending branches of the curve are symmetrical. Besides, it resulted that during full Moon all the regions of the lunar surface with an identical albedo have an identical brightness. Hence it follows that if the whole of the lunar surface had the same albedo, the Moon when full would appear to be a uniformly illuminated disk.

Based on a study of light reflection from rough, porous surfaces covered with multi-sized grains, all the above-described peculiarities of the law of light reflection from the lunar surface were explained by the author as a result of extreme porosity, scarring and roughness of the lunar surface. It turned out that scarring (microrelief) of the lunar surface was so great that the standard terrestrial rocks, excluding spongeous tuffs, which correspond somewhat to the microrelief of the Moon, do not resemble the lunar surface rocks. Indicatrices constructed for the "intensity equator" of the Moon by N. S. Orlova (6) as well as by N. P. Barabashov and V. I. Garazha (7) also attested to the same condition. According to Orlova, indicatrices of continents and seas nearly coincide, while those of Barabashov and Garazha are more elongated for the continents than for the seas, which condition points to greater scarring in the continental regions.

Further studies (by N. P. Barabashov, A. T. Chekrida (8), V. A. Fedorets (9), V. V. Sharonov (10), N. N. Sytinskaya (11) and others) agree with the conclusions made at the Kharkov Astronomical Observatory concerning the intensive scarring of the entire lunar surface.

Research on various artificial surfaces, covered with varying irregularities, led us to conclude that the best agreement with lunar observations is yielded by surfaces covered with sharp-ended rough spots and parallel fissures.

It was further clarified that fine dust uniformly covering a smooth surface cannot yield the light reflection effects observed on the Moon, since the law of reflection from a fragmented substance approaches the Lambert law as the coarseness of the grains diminishes.

Barabashov, Yezerskiy, Yezerskaya and Ishutina (12) completed a study of the photometric homogeneity of lunar sectors, encompassing various types of lunar objects as well as various parts of the lunar disk. The Helmholtz principle of optical reciprocity was used for this purpose. The correlation which must be satisfied by the brightness of two sectors of the Moon when their surfaces have identical reflecting capabilities, was arrived at by Minnaert (13). Eighty-four comparisons were made, and at final presentation of the results, all sectors' details were divided into three groups: (1) seas, swamps, gulfs; (2) continents, craters; (3) light rays.

When comparing the objects belonging to one group of lunar formations, the mean deflection is small and notably smaller than at comparison of objects belonging to different groups. Thus the greatest deflections are revealed at photometric comparison of seas and continents with one another. On an average, the seas and continents show a difference in scattering properties or in the photometric structure of light rays in comparison with those regions, through which they pass. The impression is created that light rays adopt the photometric structure of the regions along which they fall. We thus can conclude that on an average, the lunar surface is photometrically homogeneous, although seas and continents differ slightly from each other. In some cases, this difference is relatively small. Hence, the conclusion follows that the lunar surface is,on an average, endowed with a single degree of porosity.

The photometric structure of the lunar surface results from the action of internal forces, determining macro-and microrelief, as well as from that of external forces provided with greater action isotropy, and able to exert a substantial influence on microstructure. The photometric uniformity which was revealed gives evidence of this. It may consequently be said that in the presence of a general uniformity, lunar seas and continents are still endowed with notable differences: (1) Continents are on an average more reddish than seas. (2) The porosity of the continents is on an average greater than that of the seas.

Photometric investigations of crushed tuff carried out at the Kharkov Astronomical Observatory, and a study of light reflection not only from angles of its incidence and reflection, but also of its azimuth between the incident and the reflected ray, have further corroborated the opinion that the lunar surface is covered with irregularly arranged grains whose dimensions range from 1 to 6 mm. Investigation of the Moon with the help of decimeter waves, for which the Moon still appears smooth (14, 15), leads to the same results. N. N. Sytinskaya (11) assumes that the irregularities conditioning the lunar microrelief are within the 1 to 10 mm. range.

All that has been stated above refers to the side of the Moon visible from the Earth. What the structure of the other side may be, and what peculiarities characterize that part of its surface has been unknown until recently, although many astronomers advanced various assumptions about it. They considered that the areas of the far side of the Moon, occupied by seas are as broad as on its visible side, and that craters and cirques are just as numerous. The inference is that the visible and far sides scarcely differ. Others expressed the opinion that the invisible side of the Moon, always faced away from the Earth, must differ from the visible side. But all these assumptions could not pretend to be at all reliable, for they were based on quite tenuous foundations. At the same time, an understanding of the structure of the Moon's far side and of the peculiarities of its relief is of substantial interest. That is why the direct photographing of the far side of the Moon, carried out with the aid of the automatic interplanetary station (AIS) on 7 October 1959, has great significance for a comprehensive study of our natural satellite, and is a historical feat of utmost importance.

Let us recall that photographing the reverse side of the Moon aboard the AIS began on 7 October 1959 at 0630 hours Moscow time, and lasted 40 minutes. The selenographic coordinates of the AIS and its distance from the center of the Earth for the moments of the beginning and of the end of photographing were respectively $\beta_1 = +16°,9$; $\lambda_1 = +117°,9$; $R_1 = 65\ 200$ км and $\beta_2 = +17°,3$; $\lambda_2 = 117°,1$; $R_2 = 68\ 400$ км.

The photographing was carried out with the help of two objectives with focal distances of 200 to 500 mm. The pictures were transmitted to the Earth with the aid of television devices, and photographed again on the ground.

From a preliminary study, we could ascertain that mountain regions predominate on the far side of the Moon. Seas similar to those located on its visible part are scarce. A fairly large crater sea about 300 km in diameter, and situated between the latitudes $\beta = +20°$, $\beta = +30°$ and longitudes $\lambda = \pm 140°$, $\lambda = \pm 160°$ was detected here, and designated as the "Moscow Sea". This sea has a gulf, called "Astronauts' Gulf". All the region of the far side of the Moon, contiguous to its western edge, has an albedo intermediate between that of mountainous regions and that of sea regions of its visible side (16).

It should be noted that craters (except those near the terminator), have very smooth, eroded outlines. This is explained by the fact that the Moon was at time of photographing in a position near the full moon (in relation to the AIS). Moreover, we know that during the full moon phase, craters are seen by a ground observer as weak, light rings, only weakly outlined, and showing at times a darker bottom. This circumstance, i. e. the lack of relief, has considerably hindered the identification of details, and the determination of their character. However, in the southern hemisphere of the Moon, a large crater, with a diameter of more than 100 km, is clearly and sharply outlined in the region with the coordinates $\beta = -20 \div -30°$ and $\lambda = +30°$. This crater has been termed the "Tsiolkovskiy Crater". It merits special attention for it has a particularly dark bottom and an exclusively bright central hill: the brightness of the central hill is quite great, and one is led to wonder whether or not it might be self-luminescent.

A light line, consisting of a band of craters and hills, extends southeast of Humboldt Sea. This band is interrupted in places by darker intervals. It has the form of a range extending for almost 2000 km. A bright band resembling a light beam also extends in the same direction.

The results of processing the photographic material at the Kharkov Observatory were as follows. All the details revealed during the first stage of the processing were quite practicable and thus did not cause any doubts. Besides, new craters were found, sharply outlined at the terminator, and boundaries of certain seas were made more precise. The final results of the combined processing by the Shternberg State Astronomical Institute in Moscow, the Principal Astronomical Observatory in Pulkovo, and in the Kharkov Astronomical Observatory have led to the revelation of more than 400 details, and were presented in the Atlas of the Far Side of the Moon (17).

From the examination and from the subsequent processing of the photographs at the Kharkov University Astronomical Observatory (18, 19), we can conclude that:

1. The invisible part of the Moon photographed by means of the AIS differs from the visible part directed toward the Earth: the former

is covered by a great number of craters, while the seas are very few.

2. The albedo of many regions of the far side of the Moon is substantially increased.

3. The bottom of many craters is very dark, and it compares in degree of darkness with the darkest regions of the visible part of the Moon.

4. There extends over the far side of the Moon, to the south-southeast of the Humboldt Sea, an enormous and very bright light beam originating from a crater surrounded by a bright glow.*

5. The central hill of certain craters has such a great degree of brightness, that the possibility of luminescence is suggested.

6. Preliminary investigations suggest that the porosity (microrelief) of the surface of the Moon's far side is the same if not greater than that of the visible side, and the distribution of brightness over the surface of the full Moon visible from the AIS, is represented by an almost straight line.

Received 15 September 1960

Translated by Andre L. Brichant
for National Aeronautics and
Space Administration Headquarters

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